The Grants Uranium District, New Mexico: Update on Source, Deposition, and Exploration[1]

VIRGINIA T. McLEMORE[2]

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2. NM Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM, 87801; ginger@gis.nmt.edu

ABSTRACT

More than 340 million pounds (lbs) of U_3O_8 have been produced from the Grants uranium deposits in New Mexico between 1948 and 2002, and at least 403 million lbs of U_3O_8 remain as unmined resources. The Grants district is one of the largest uranium provinces in the world. The Grants district extends from east of Laguna to west of Gallup in the San Juan Basin of New Mexico.

Three types of sandstone uranium deposits are recognized: tabular, redistributed (roll-front, fault-related), and remnant-primary. The tabular deposits formed during the Jurassic Westwater Canyon time. Subsequently, oxidizing solutions moved downdip, modifying tabular deposits into redistributed roll-front and fault-related deposits. Evidence, including age dates and geochemistry of the uranium deposits, suggests that redistributed deposits could have been formed shortly after deposition in the early Cretaceous and from a second oxidation front during the mid-Tertiary.

The source of uranium is important in understanding how the Grants deposits formed. Two possible sources exist: 1) the Zuni Mountains, which lie south of the district and consist of a Proterozoic granitic highland enriched in uranium with as much as 11 parts per million, and with high heat flow; and 2) volcanic rocks erupted from a Jurassic arc volcanism, which formed southwest of the San Juan Basin, and deposited ash over much of the region. Uranium was likely leached from the Jurassic volcanic rocks, Jurassic ash, and the Precambrian granites; these leaching waters then migrated into the San Juan Basin. Leaching waters then mixed with pore water containing uranium that was leached from the detrital volcanic ash in the host sediments. The uraniferous groundwater migrated into the Westwater Canyon sandstones and precipitated in the vicinity of humate and other organic material to form the tabular uranium deposits. The recognition that there are different sources of uranium and different mechanisms of uranium deposition, aids in understanding the complexity and local variations within the tabular deposits. These deposit characteristics had a major impact on the remobilization and redistribution of uranium to form the redistributed deposits.

Although several companies continue to be active in the district, future resource development will depend upon lowering production costs, perhaps by in situ recovery techniques, and the resolution of regulatory issues.

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Virginia T. McLemore

INTRODUCTION

During a period of nearly three decades (1951-1980), the Grants uranium district in northwestern New Mexico (Fig. 1) yielded more uranium than any other district in the United States (Tables 1, 2). Although there are no producing operations in the Grants district today, extensive reserves and resources remain in the district (Table 3). Many deposits in the Grants district were defined in the 1970s and 1980s but not mined because of the decrease in demand and price of uranium in the 1980s. Numerous companies have acquired uranium properties (Table 3; McLemore, 2007) and plan to explore and develop deposits in the district in the near future using both conventional and in situ recovery technology.

The Grants uranium district in the San Juan Basin extends from east of Laguna to west of Gallup, New Mexico and consists of eight subdistricts (Fig. 1; McLemore and Chenoweth, 1989). The Grants district is probably fourth in total world production behind East Germany, Athabasca Basin in Canada, and South Africa (Tom Pool, 2002, General Atomics, Denver, Colorado, written comm.). Most of the uranium production in New Mexico has come from the Jurassic Westwater Canyon Member of the Morrison Formation of the San Juan Basin located in McKinley and Cibola (formerly Valencia) counties (Table 2; McLemore, 1983).

Although there are many previous studies addressing the formation of the Grants uranium deposits, some questions remain, including:

- What is the spatial and temporal distribution of the uranium deposits in the Grants district?
- What is the source of the uranium in the Grants district?
- What is the economic potential of the deposits in the Grants district?

The purpose of this report is to briefly describe the general types of uranium deposits and their mining history, production, geology, resources, deposition, source and future economic potential in the Grants district of New Mexico. Much of this report is summarized from McLemore (1983, 2007), McLemore and Chenoweth (1989, 2003), McLemore et al. (2002), and other reports as cited. Information on specific mines and deposits in New Mexico can be found in cited references McLemore (1983), and McLemore et al. (2002).

HISTORY AND PRODUCTION

Interest in uranium as a commodity began in the early 1900s, however, several deposits in New Mexico were discovered and mined originally for radium. Radium was produced from the White Signal district in Grant County (Gillerman, 1964) and the Scholle district in Torrance, Socorro, and Valencia counties (McLemore, 1983). Exact production figures are unknown, but are probably very small.

John Wade of Sweetwater, Arizona first discovered uranium and vanadium minerals in the Saltwash Sandstone Member of the Morrison Formation in the Carrizo Mountains, located in the northwestern San Juan Basin, about 1918 (Chenoweth, 1993, 1997). At that time, the Navajo Reservation was closed to prospecting and mining. On June 30, 1919, a Congressional Act opened the reservation to prospecting and locating mining claims in the same manner as prescribed by the Federal mining law (Chenoweth and McLemore, 2010). The area remained inactive from 1927 to 1942. In 1942, the Vanadium Corporation of America (VCA) was the highest bidder for vanadium in the east Carrizo Mountains, called the East Reservation Lease (no. I-149-IND-5705). Uranium in the vanadium ore was secretly recovered via a uranium circuit at the Monticello mill (Utah) for the Manhattan Project in 1943-1945. The total amount of recovered uranium is estimated at 44,000 pounds (lbs) U_3O_8, mostly from King Tutt Mesa (Chenoweth, 1985a). Mining ceased in the east Carrizo Mountains in 1967.

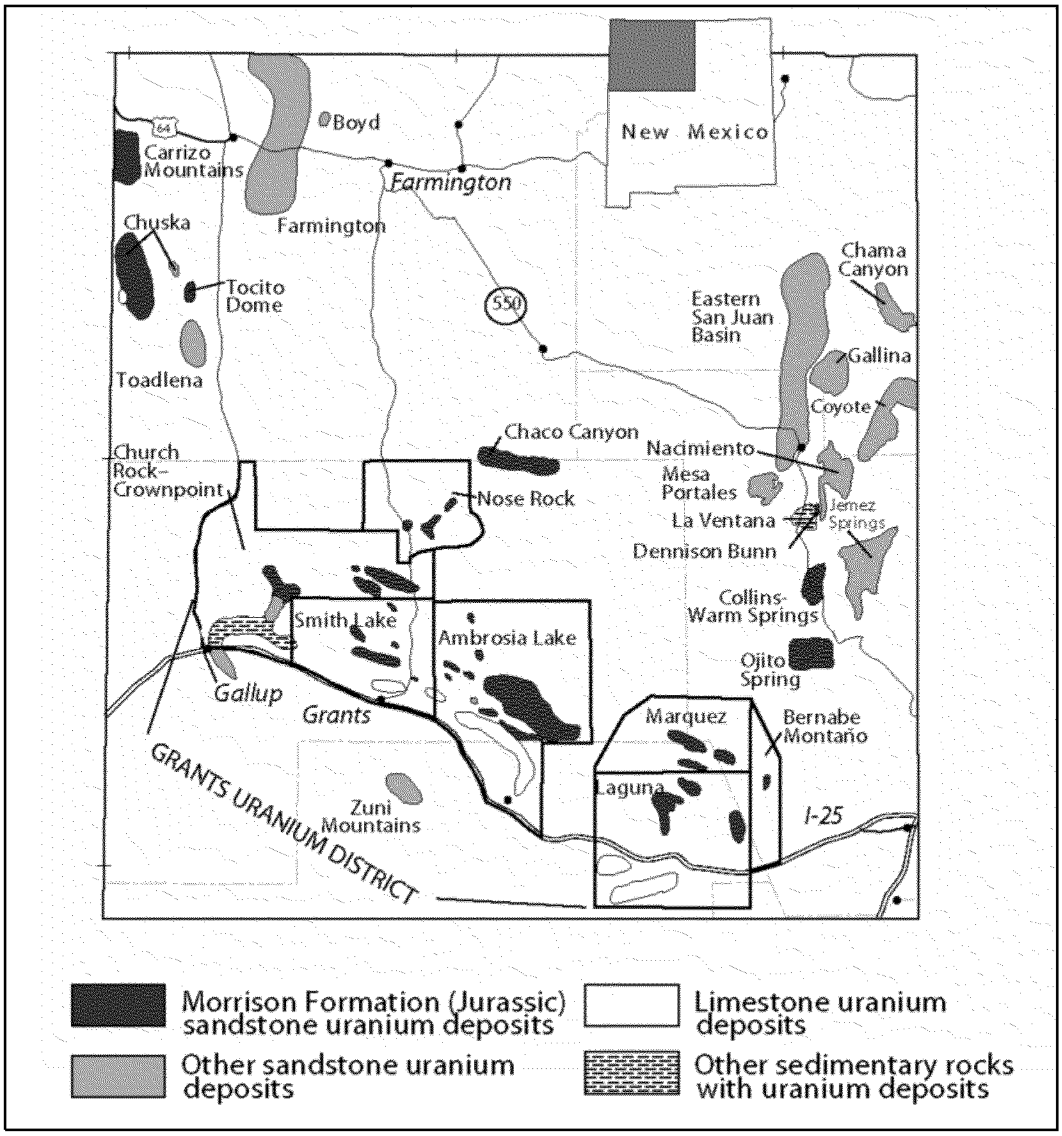

Figure 1. Subdistricts in the Grants uranium district, San Juan Basin, New Mexico. Polygons outline approximate areas of known uranium deposits.

The United States (US) Atomic Energy Commission (AEC) was created in 1947. From 1948 through 1966, the AEC purchased all of the uranium concentrate produced in New Mexico from buying stations. During the last few years of the AEC program (1967-1970), the AEC allowed mill operators to sell uranium to electric utilities. In New Mexico this amounted to over 17.4 million lbs of U_3O_8 (Albrethsen and McKinley, 1982). The price schedules, bonuses, and other incentives offered by the AEC created a prospecting boom that spread across the Four Corners area to all parts of New Mexico. Discoveries were made in the Saltwash Sandstone Member in the Chuska Mountains near Sanostee (McLemore and Chenoweth, 1997; Chenoweth and McLemore, 2010), and in the Todilto limestone near Grants (Berglof and McLemore, 2003). The announcement of Paddy Martinez's discovery of uranium in the Todilto limestone at Haystack Butte in 1950 brought uranium prospectors to the Grants area. It was Lewis Lothman's discovery in March 1955 at Ambrosia Lake subdistrict that created the uranium boom in the Westwater Canyon Sandstone Member in the Grants district. These discoveries led to a significant exploration effort in the San Juan Basin between Laguna and Gallup and ultimately led to the development of the Grants uranium district.

Exploration activity in the area led to active mining and mills were soon built and operated in the Grants district and at Shiprock, New Mexico. The Anaconda Bluewater mill was built at Bluewater, west of Grants in 1953, to process ores from the nearby Todilto deposits using a carbonate leach circuit until the circuit was closed in 1959. The Bluewater mill then operated an acid leach circuit to process ore from the Jackpile mine in December 1955

TABLE 1

Uranium production by type of deposit from the San Juan Basin, including the Grants district, New Mexico from 1947 through 2002 (McLemore and Chenoweth, 1989, 2003; production from 1988 to 2002 estimated by the senior author). Total United States (US) production from McLemore and Chenoweth (1989) and Energy Information Administration (2006).

Type of deposit	Production (lbs U_3O_8)	Period of production (years)	Production per total in New Mexico (percent)
Primary, redistributed, remnant sandstone uranium deposits (Morrison Formation, Grants district)	330,453,000 [1]	1951-1988	95.4
Mine-water recovery (Morrison Formation, Grants district)	9,635,869	1963-2002	2.4
Tabular sandstone uranium deposits (Morrison Formation, Shiprock district)	493,510	1948-1982	0.1
Other Morrison Formation sandstone uranium deposits (San Juan Basin)	991	1955-1959	—
Other sandstone uranium deposits (San Juan Basin)	503,279	1952-1970	0.1
Limestone uranium deposits (Todilto limestone; predominantly Grants district)	6,671,798	1950-1985	1.9
Other sedimentary rocks with uranium deposits (total NM)	34,889	1952-1970	—
Vein-type uranium deposits (total NM)	226,162	1953-1966	—
Igneous and metamorphic rocks with uranium deposits (total NM)	69	1954-1956	—
Total in New Mexico	348,019,000[1]	1948-2002	100
Total in United States	927,917,000[1]	1947-2002	37.5 of total US

[1] approximate figures rounded to the nearest 1,000 lbs. There hasn't been any uranium production from New Mexico since 2002.

(Albrethsen and McKinley, 1982). The Bluewater mill closed in 1982. The Homestake mill, 5.5 miles north of Milan, actually consisted of two mills. The southern mill, built in 1957, was known as the Homestake-New Mexico Partners mill and was closed in 1962 (Chenoweth, 1989a; McLemore and Chenoweth, 2003). The Homestake-Sapin Partners, a partnership between Homestake and Sabre Pinon Corporation (Corp.), in 1957 built a second, larger mill north of the first facility. In 1962, United Nuclear Corp. merged with Sabre Pinon Corp., but maintained the United Nuclear Corp. name. In March 1981, the United Nuclear-Homestake Partnership was dissolved and Homestake became the sole owner. The Homestake mill ceased production in 1981, but reopened in 1988 to process ore from the Section 23 mine and Chevron's Mt. Taylor mine. The mill closed soon after and was decommissioned and demolished in 1990.

In 2001, Homestake Corp. merged with Barrick Gold Corp. Homestake completed reclamation of the Homestake mill at Milan in 2004. Kermac Nuclear Fuels Corp., a partnership of Kerr-McGee Oil Industries, Incorporated (Inc.),

TABLE 2

Uranium production and types of deposits by district or subdistrict in the San Juan Basin, New Mexico (McLemore and Chenoweth, 1989; production from 1988 to 2002 estimated by the author). Some district names have been changed from McLemore and Chenoweth (1989) to conform to McLemore (2001). See McLemore (1983), McLemore and Chenoweth (1989), and McLemore et al. (2002) for more details and locations of additional minor uranium occurrences.

District	Production (lbs U_3O_8)	Grade (U_3O_8 percent)	Period of Production
Grants district			
1. Laguna	>100,600,000	0.1-1.3	1951-1983
2. Marquez	28,000	0.1-0.2	1979-1980
3. Bernabe Montaño	None		
4. Ambrosia Lake	>211,200,000	0.1-0.5	1950-2002
5. Smith Lake	>13,000,000	0.2	1951-1985
6. Church Rock-Crownpoint	>16,400,000	0.1-0.2	1952-1986
7. Nose Rock	None		
8. Chaco Canyon	None		
Shiprock district			
9. Carrizo Mountains	159,850	0.23	1948-1967
10. Chuska	333,685	0.12	1952-1982
11. Tocito Dome	None		
12. Toadlena	None		
Other areas and districts			
13. Zuni Mountains	None		
14. Boyd prospect	74	0.05	1955
15. Farmington	3	0.02	1954
18. Chama Canyon	None		
19. Gallina	19	0.04	1954-1956
20. Eastern San Juan Basin	None		
21. Mesa Portales	None		
22. Dennison Bunn	None		
23. La Ventana	290	0.63	1954-1957
24. Collins-Warm Springs	989	0.12	1957-1959
25. Ojito Spring	None		
26. Coyote	182	0.06	1954-1957
27. Nacimiento	None		
28. Jemez Springs	None		

TABLE 3

Estimated uranium resources in the Grants uranium district, New Mexico. Mine identification number (Mine id) and Subdistrict are from the New Mexico Mines Database (McLemore et al., 2002). Most deposits are delineated on maps by McLemore and Chenoweth (1991) and described in more detail by McLemore et al. (2002). (Note that the information presented is from the best data available and is subject to change as new data are obtained. Resource statistics are generally historic and not Canadian Instrument 43-101 compliant.) Host rock abbreviations are: Kd=Dakota Formation, Jm=Morrison Formation, Jj=Jackpile Sandstone, Jp=Poison Canyon Sandstone, Jb=Brushy Basin Member, Jwc=Westwater Canyon Sandstone, Js=Wanakah (Summerville) sandstone, Jt=Todilto limestone.

Mine id	Subdistrict	Mine name	Latitude	Longitude	Host Rock	Total Resources (lbs U_3O_8)	Primary Company
NMMK0003	Ambrosia Lake	Ann Lee	35.414444	107.79547	Jm-Jwc, primary	resources remain	Phillips Petroleum Co.
NMMK0008	Ambrosia Lake	Barbara J 2	35.32832	107.83393	Jt	resources remain	Mid-Continent Uranium Corp.
NMMK0009	Ambrosia Lake	Barbara J 3	35.333098	107.82497	Jt	resources remain	Todilto Exploration and Development Co.
NMBE0047	Ambrosia Lake	Bernabe	35.210595	106.96538	Jwc	11,540,000	
NMSA0023	Ambrosia Lake	Bernabe	35.227611	107.01086	Jwc, primary, redistributed	1,500,000	Laguna Pueblo
NMMK0020	Ambrosia Lake	Borrego Pass	35.620119	107.94362	Jwc, primary	45,000,000	Conoco
NMMK0025	Church Rock-Crownpoint	Canyon	35.656988	108.20692	Jwc, redistributed	600,000	
NMMK0034	Church Rock-Crownpoint	Church Rock (Section 17)	35.622209	108.55273	Jwc, Kd, redistributed	8,443,000	Uranium Resources Inc. (HRI)
NMMK0033	Church Rock-Crownpoint	Church Rock 8, 2		35.606229	108.58616	Jwc	resources remain
NMMK0128	Church Rock-Crownpoint	Church Rock ISL (Section 8)	35.630313	108.55064	Jwc, redistributed	6,529,000	Uranium Resources Inc. (HRI)
NMMK0316	Church Rock-Crownpoint	Church Rock-Section 4	35.642301	108.53346	Jwc, redistributed	11,848,007	Strathmore
NMMK0035	Ambrosia Lake	Cliffside (Frosty Ox)	35.395569	107.74929	Jwc, primary, breccia pipe	resources remain	Trans America Industries, Neutron Energy
NMMK0036	Church Rock-Crownpoint	Crownpoint	35.68475	108.16042	Jwc	resources remain	originally Conoco, Uranium Resources Inc.
NMMK0039	Church Rock-Crownpoint	Crownpoint	35.680444	108.13092	Jwc	resources remain	Conoco, Uranium Resources Inc.
NMMK0038	Church Rock-Crownpoint	Crownpoint	35.71751	108.22681	Jwc, primary	resources remain	Mobil (Nufuels)
NMMK0040	Church Rock-Crownpoint	Crownpoint ISL (Unit 1)	35.706678	108.22052	Jwc, primary	27,000,000	Mobil-TVA

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TABLE 3 (cont'd)

Mine id	Subdistrict	Mine name	Latitude	Longitude	Host Rock	Total Resources (lbs U_3O_8)	Primary Company
NMMK0346	Church Rock-Crownpoint	Crownpoint-Section 24	35.684585	108.1677	Jwc, primary	38,959,000	Uranium Resources Inc.
NMMK0043	Church Rock-Crownpoint	Dalton Pass	35.678492	108.26496	Jwc, redistributed	600,000	United Nuclear-TVA
NMMK0044	Church Rock-Crownpoint	Dalton Pass	35.681298	108.27829	Jwc, redistributed	200,000	United Nuclear-TVA
NMCI0251	Ambrosia Lake	East Area	35.279174	107.74755	Jp	388,434	Laramide Resources
NMMK0712	Ambrosia Lake	East Roca Honda	35.373201	107.65319	Jwc, primary	resources remain	Trans America Industries Ltd.
NMCI0012	Ambrosia Lake	F-33 (Grants Ridge)	35.219167	107.78369	Jt	resources remain	Uranium Energy Corp.
NMMK0065	Ambrosia Lake	Fernandez-Main Ranch	35.348611	107.66456	Jwc, primary	850,000	Gulf
NMMK0711	Smith Lake	Hosta Butte	35.64592	108.20164	Jwc, redistributed	14,822,000	Quincy
NMMK0087	Ambrosia Lake	Johnny M	35.362444	107.72219	Jwc, primary	3,500,000	Ranchers Exploration
NMMK0088	Marquez	Juan Tafoya-Marquez Grant	35.313362	107.31706	Jwc	751,000	Neutron Energy Inc.
NMCI0019	Laguna	L Bar (JJ)	35.175458	107.32655	Jj	12,653,000	Neutron Energy Inc.; Uranium Energy Corp.
NMCI0020	Ambrosia Lake	La Jara Mesa	35.280139	107.74489	Jp	7,257,817	Laramide Resources
NMMK0094	Ambrosia Lake	Lee	35.360222	107.70275	Jwc	9,620,000	Roca Honda-Kerr-McGee
NMMK0101	Church Rock-Crownpoint	Mancos-Section 12	35.626449	108.58327	Jwc, redistributed	11,300,000	Strathmore
NMMK0100	Church Rock-Crownpoint	Mancos-Section 7	35.628936	108.58055	Jwc, redistributed	4,164,000	Uranium Resources Inc.
NMMK0102	Smith Lake	Mariano Lake	35.547083	108.278	Jb	840,000	Gulf
NMMK0105	Ambrosia Lake	Marquez	35.343326	107.75994	Jp	resources remain	United Nuclear
NMMK0104	Marquez	Marquez Canyon	35.32425	107.33005	Jwc	9,130,343	Kerr-McGee, TVA
NMMK0103	Marquez	Marquez Canyon (Bokum)	35.319194	107.32433	Jwc	10,700,000	Neutron Energy
NMSA0057	Marquez	Marquez Grant	35.305139	107.2908	Jwc, primary	676	
NMMK0245	Ambrosia Lake	Melrich (Section 32)	35.394462	107.70806	Jwc, primary	3,217,000	Homestake

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TABLE 3 (cont'd)

Mine id	Subdistrict	Mine name	Latitude	Longitude	Host Rock	Total Resources (lbs U_3O_8)	Primary Company
NMRA0057	Coyote	Mesa Alta (Yeso)	36.220833	106.66239	Jt	resources remain	Magnum Uranium Corp.
NMCI0027	Ambrosia Lake	Mt. Taylor	35.334977	107.63558	Jwc, primary, redistributed?	30,250,000	Rio Grande Resources Corp., General Atomics
NMMK0111	Church Rock-Crownpoint	Narrow Canyon	35.644836	108.29841	Jwc, primary	828,000	Pioneer Nuclear
NMMK0117	Church Rock-Crownpoint	NE Church Rock	35.658409	108.50853	Jwc, redistributed	2,250,000	United Nuclear Corp.
NMMK0112	Church Rock-Crownpoint	NE Church Rock 1	35.666496	108.50273	Jwc, primary, redistributed	708,589	Navajo Nation Indian Reservation
NMMK0114	Church Rock-Crownpoint	NE Church Rock 2	35.676632	108.52621	Jwc, primary	2,850,000	Kerr-McGee
NMMK0115	Church Rock-Crownpoint	NE Church Rock 3	35.697561	108.54866	Jwc, primary	4,200,000	Kerr-McGee
NMMK0119	Nose Rock	Nose Rock	35.884364	107.99161	Jwc, primary, redistributed?	21,900,000	Uranium Resources Inc.
NMMK0122	Nose Rock	Nose Rock	35.830361	108.06414	Jwc	3,620,000	Phillips Petroleum Co.
NMMK0350	Nose Rock	Nose Rock	35.844966	108.05007	Jwc	2,070,800	Phillips Petroleum Co.
NMMK0120	Nose Rock	Nose Rock 1	35.83556	108.05528	Jwc, primary, redistributed?	14,017,298	Strathmore
NMSA0074	Ambrosia Lake	Rio Puerco	35.271444	107.19803	Jwc, primary	11,362,640	Ausamerican Mining
NMMK0142	Ambrosia Lake	Roca Honda	35.365717	107.6966	Jwc, primary	17,512,000	Strathmore
NMMK0143	Ambrosia Lake	Roca Honda	35.363139	107.69961	Jwc, primary	14,700,000	Uranium Resources Inc.
NMCI0046	Laguna	Saint Anthony	35.159088	107.30614	Jt	8,208,000	51 percent Neutron Energy Inc., 49 percent Uranium Energy Corp.
NMCI0050	Marquez	San Antonio Valley	35.256361	107.25844	Jwc	resources remain	
NMMK0149	Ambrosia Lake	Sandstone	35.396194	107.769	Jwc, primary	resources remain	United Nuclear Corp.
NMMK0179	Ambrosia Lake	Section 13	35.348778	107.63547	Jp	resources remain	Uranium Resources Inc.
NMMK0198	Ambrosia Lake	Section 18	35.44625	107.93733	Jwc	resources remain	Trans America Industries Ltd.
NMMK0210	Ambrosia Lake	Section 24 (Treeline)	35.347278	107.74672	Jb	resources remain	Western Uranium Corp.

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TABLE 3 (cont'd)

Mine id	Subdistrict	Mine name	Latitude	Longitude	Host Rock	Total Resources (lbs U_3O_8)	Primary Company
NMMK0222	Ambrosia Lake	Section 26	35.408972	107.76286	Jwc, primary	resources remain	Trans America Industries Ltd.
NMMK0223	Ambrosia Lake	Section 26	35.40776	107.75696	Jwc, primary	resources remain	Kerr-McGee
NMMK0239	Ambrosia Lake	Section 31 (Frosty Ox)	35.398194	107.72336	Jwc	1,002,160	Trans America Industries, Neutron Energy
NMMK0126	Church Rock-Crownpoint	Section 32-Dalton Pass	35.664222	108.23567	Jwc, redistributed	1,529,823	
NMMK0250	Ambrosia Lake	Section 35 (Elizabeth)	35.398861	107.75842	Jwc, primary	resources remain	Quivira Mining Company (Rio Algom LLC)
NMMK0251	Ambrosia Lake	Section 36 (Ambrosia Lake)	35.399083	107.73394	Jwc, primary, redistributed	resources remain	Neutron Energy
NMCI0056	Ambrosia Lake	Section 4	35.296777	107.78773	Jt	Minor reserves remaining	Uranium Energy Corp.
NMMK0170	Ambrosia Lake	Section 6 (Mesa Redonda)	35.46975	107.92969	Jwc	resources remain	Trans America Industries Ltd.
NMMK0173	Ambrosia Lake	Section 8	35.461639	107.92347	Jwc	resources remain	Trans America Industries Ltd.
NMCI0057	Ambrosia Lake	Section 9	35.288667	107.79544	Js, Jt	resources remain	Uranium Energy Corp.
NMMK0338	Ambrosia Lake	Vanadium	35.333391	107.85629	Jm	2,500,000	
NMMK0340	Ambrosia Lake	West Largo	35.5257	107.92151	Jwc	19,600,000	Gulf, Santa Fe Industries, Strathmore
NMMK0247	Smith Lake	West Ranch (Begay Allotment)	35.490389	108.01622	Jwc, redistributed	2,600,000	United Energy Corp.
Total						403,122,587	

Anderson Development Corp., and Pacific Uranium Mines Company (Co.), built the Kerr-McGee mill at Ambrosia Lake in 1957-1958. In 1983, Quivira Mining Co., a subsidiary of Kerr-McGee Corp. (later Rio Algom Mining LLC, currently BHP-Billiton) became the operator. The mill began operating in 1958 and from 1985-2002, the mill produced only from mine waters from the Ambrosia Lake underground mines. Quivira Mining Co. is no longer producing uranium and the Ambrosia Lake mill and mines are being reclaimed. Phillips Petroleum Co. also built a mill at Ambrosia Lake in 1957-58. United Nuclear Corp. acquired the property in 1963, when the mill closed. The Department of Energy (DOE) remediated the site between 1987 and 1995 as part of the Uranium Mill Tailings and Remediation Act (UMTRA) of 1978. Additional mills were built in the Shiprock, Laguna, and Church Rock areas and are currently being reclaimed (McLemore and Chenoweth, 2003).

Annual uranium production in New Mexico increased steadily from 1948 to 1960, from 1965 to 1968, and from 1973 to 1979. Peak production was attained in 1978, with a record yearly production of 9,371 tons of U_3O_8 that was shipped to mills and buying stations (McLemore, 1983;

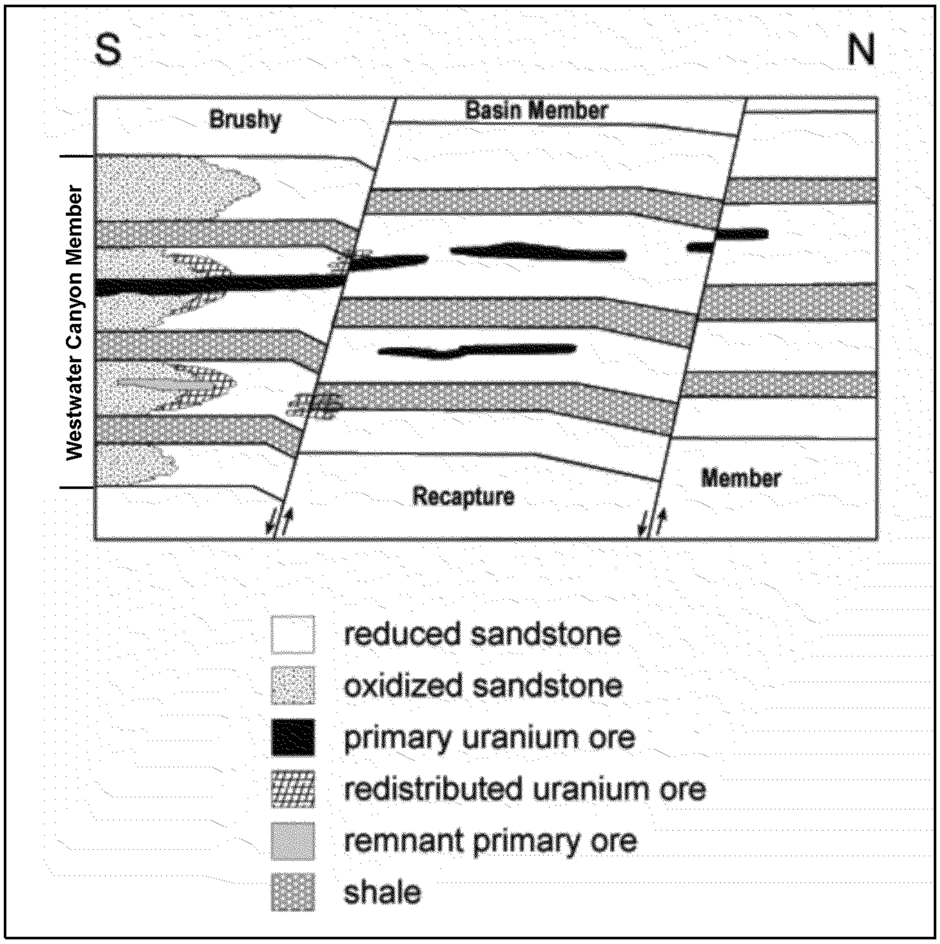

Figure 2. Sketch of the different types of uranium deposits found in the Morrison Formation. See text for description.

McLemore and Chenoweth, 1989, 2003). Production from mine-water recovery from underground mines by Quivira Mining Co., formerly Kerr-McGee Corp., amounted to 9,635,869 lbs of U_3O_8 from 1963-2002 (Table 1).

All of the conventional underground and open-pit mines in New Mexico closed by 1989 for several reasons:

- The Three Mile Island incident resulted in finalizing a growing public perception in the US that nuclear power was dangerous and costly; subsequently nuclear power plants became unpopular.
- There was an overproduction of uranium in the 1970s through the early 1980s that led to large stockpiles of uranium. In addition, the dismantling of nuclear weapons by the US and Russia also increased these stockpiles, reducing the need for mining uranium.
- New Mexico uranium deposits in production were decreasing in grade by nearly half during the 1980s.
- The cost of mine and mill reclamation was increasing in cost and was not accounted for in original mine plans and mill contracts, making the existing mines uneconomic.
- Higher grade, more attractive uranium deposits were found elsewhere in the world.
- Large coal deposits were found throughout the US in the 1970s that could meet the nation's energy needs, and the nation shifted to coal-fired electrical plants in response to the Three Mile Island incident.

The decline in the price of uranium during 1989-2005 resulted in no uranium production (except mine-water recovery), exploration, or development in the district. Many companies reclaimed and / or sold their properties. However, today with the recent increase in price and demand for uranium, numerous companies are acquiring new and old properties and exploring for uranium in the Grants district.

The Grants district is once again an attractive area for uranium exploration. Some reasons for this are:

- Major companies abandoned properties in the district after the last cycle leaving advanced uranium projects with delineated resources.
- Current property acquisition costs are inexpensive because the properties include millions of dollars worth of exploration and development expenditures.

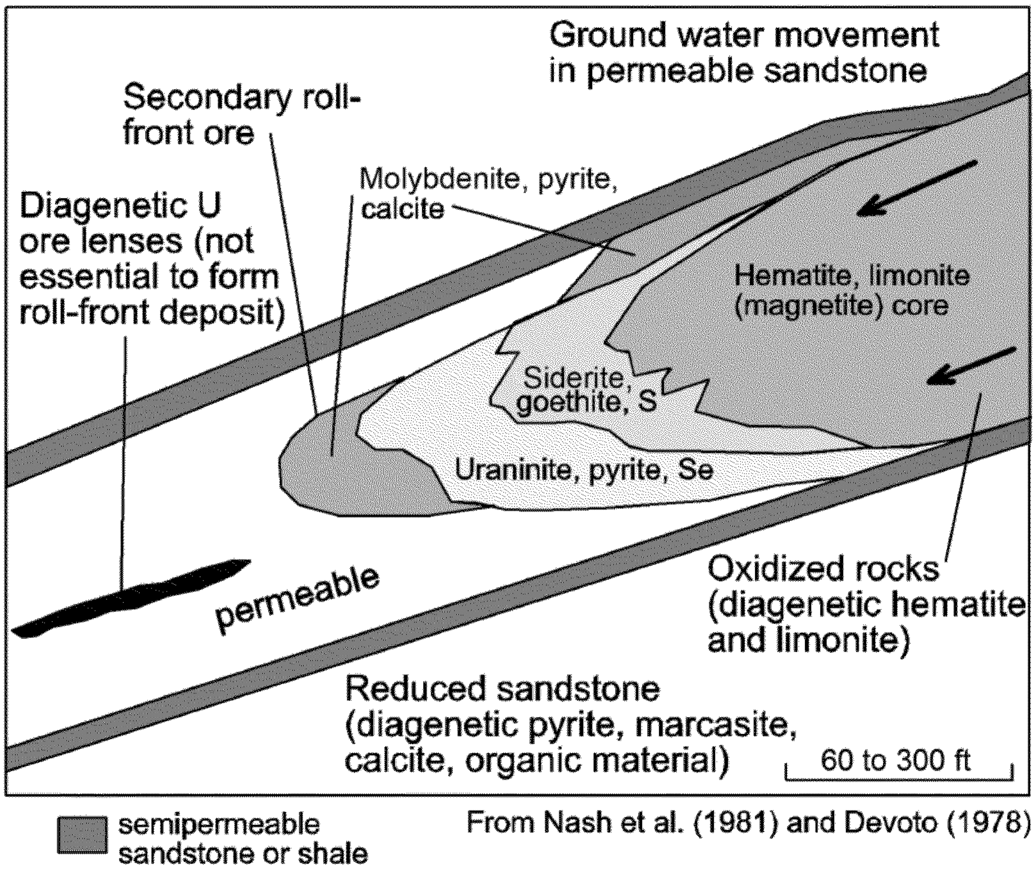

Figure 3. Sketch of the formation of redistributed sandstone uranium deposits in the Grants district. See text for description. Abbreviations used: S=sulfur; Se=selenium; U=uranium.

- Data and technical expertise on these properties are available.
- Recent advances in in situ leaching, heap leaching, and milling technology allow for the Grants district sandstone uranium deposits to be economically attractive.

TYPES OF URANIUM DEPOSITS IN THE GRANTS DISTRICT

The most important type of deposit in terms of production and resources in the San Juan Basin of New Mexico are sandstone uranium deposits in the Jurassic Morrison Formation. Other types of deposits have yielded uranium ore (McLemore and Chenoweth, 1989).

Sandstone Uranium Deposits in the Jurassic Morrison Formation

The most significant deposits are those in the Morrison Formation, specifically the Westwater Canyon Member, where more than 340,088,869 lbs of U_3O_8 were produced from the Morrison Formation from 1948 to 2002, including mine-water recovery (Table 1). In contrast, production from other sandstone uranium deposits in New Mexico amounts to 503,279 lbs of U_3O_8 (Table 1, 1952-1970; McLemore and Chenoweth, 1989). Other sandstone uranium deposits in New Mexico include sedimentary copper with uranium, roll-front sandstone deposits in Cretaceous and Tertiary sandstones, sedimentary uranium deposits, and beach-placer sandstone deposits; these are described in McLemore (1983) and McLemore and Chenoweth (1989).

There are three types of deposits in the Westwater Canyon Member of the Morrison Formation: primary (trend or tabular), redistributed (stack), and remnant-primary sandstone uranium deposits (Figs. 2, 3). Primary sandstone-hosted uranium deposits, also known as pre-fault, trend, blanket, and black-band ores, are found as blanket-like, roughly parallel ore bodies along trends, mostly in sandstones of the Westwater Canyon Member. These ore bodies are characteristically less than 8 feet (ft) thick, average more than 0.20 percent U_3O_8, and have sharp ore-to-waste boundaries (Fig. 2). The largest ore bodies in the Grants uranium district contain more than 30 million lbs of U_3O_8 (Table 3; McLemore et al., 2002). These are some of the highest grade sandstone uranium deposits in the world and are unusual in their association with humates (International Atomic Energy Agency, 2009).

Redistributed sandstone-hosted uranium deposits, also known as post-fault, stack, secondary, and roll-type ores, are younger than the primary sandstone-hosted uranium deposits. They are discordant, asymmetrical, irregularly shaped, characteristically more than 8 ft thick, have diffuse ore-to-waste contacts, and cut across sedimentary structures. The average deposit contains approximately 18.8 million lbs U_3O_8 with an average grade of 0.16 percent (Table 3; McLemore et al., 2002). Some redistributed uranium deposits are vertically stacked along faults (Fig. 2). Other deposits are similar in form to typical roll-front uranium deposits (Fig. 3).

Remnant sandstone-hosted uranium deposits were preserved in sandstone after the oxidizing waters that formed redistributed uranium deposits had passed. Some remnant sandstone-hosted uranium deposits were preserved because they were surrounded by or were found in less permeable sandstone and could not be oxidized by the groundwaters. Other deposits were cemented by calcite and quartz and subsequent fluids could not oxidize those deposits. These deposits are similar to primary sandstone-hosted uranium deposits, but are difficult to locate because they occur sporadically within the oxidized sandstone. The average size is approximately 2.7 million lbs U_3O_8 at a grade of 0.20 percent (McLemore and Chenoweth, 1991).

The majority of the proposed models for the formation of the primary uranium deposits in the Morrison Formation suggest that deposition occurred at a groundwater interface between two fluids of different chemical compositions and / or oxidation-reduction states. More recent models, such as the lacustrine-humate and brine-interface models, have refined or incorporated portions of early theories on the origin of the uranium deposits. No consensus has developed on details of the deposit models describing the origin of the Morrison primary sandstone uranium deposits (Nash et al., 1981; Sanford, 1992).

In the lacustrine-humate model, groundwater was expelled by compaction from lacustrine muds formed by a large playa lake into the underlying fluvial sandstones where humate or secondary organic material precipitated as a result of flocculation into tabular bodies. During or after precipitation of the humate bodies, uranium was precipitated from groundwater (Turner-Peterson, 1985; Fishman and Turner-Peterson, 1986). This model proposes the humate bodies were formed prior to uranium deposition.

In the brine-interface model, uranium and humate were deposited during compaction and diagenesis by reduction at the interface of meteoric freshwater and groundwater brines (Granger and Santos, 1986). In another variation of the brine-interface model, groundwater flow is driven by gravity, not compaction. Groundwater flowed downdip and discharged in the vicinity of the uranium deposits. Uranium precipitated in the presence of humates at a gravitationally-stable interface between relatively dilute, shallow meteoric water and saline brines that migrated updip from deeper in the basin (Sanford, 1982, 1992). Modeling of the regional groundwater flow in the Colorado Plateau during Late Jurassic and Early Cretaceous times supports the brine-interface model (Sanford, 1982). The groundwater flow was impeded by upthrown blocks of Precambrian crust and forced upwards. These zones of upwelling are closely associated with uranium-vanadium deposits throughout the Colorado Plateau (Sanford, 1982).

In the Grants district, the bleaching of the Morrison Formation sandstones and the geometry of tabular uranium-vanadium bodies located in the middle of the sandstone beds support the reaction of two chemically different waters, most likely a dilute meteoric water and saline brine from deeper in the basin. The intimate association of uranium-vanadium minerals with organic material indicates that the uranium and vanadium were deposited at the same time. Cementation and replacement of feldspar and quartz grains with uranium-vanadium minerals are consistent with deposition during early diagenesis.

During the Tertiary, after formation of the primary sandstone uranium deposits, oxidizing groundwaters migrated through the uranium deposits and remobilized some of the primary sandstone uranium deposits (Saucier, 1981). Uranium was reprecipitated ahead of the oxidizing waters forming redistributed sandstone uranium deposits. Where the sandstone host surrounding the primary deposits was impermeable and the oxidizing waters could not dissolve the deposit, remnant-primary sandstone uranium deposits remain (Figs. 2, 3).

Sandstone uranium deposits are found in other formations in New Mexico, but to date, were insignificant compared to the Morrison Formation deposits (McLemore and Chenoweth, 1989). Some companies are once again exploring in these units, especially in the Baca and Crevasse Canyon formations in the Riley-Pietown areas, Socorro and Catron counties, and in the Ojo Alamo Sandstone in the Mesa Portales area, Sandoval County (McLemore and Chenoweth, 1989). Uranium reserves and resources remain in the Grants uranium district that could be mined in the future by conventional underground techniques and by in situ leaching technologies (Table 3; Holen and Hatchell, 1986, McLemore and Chenoweth, 1991, 2003).

Tabular Sandstone Uranium-Vanadium Deposits in the Salt Wash and Recapture Members

Tabular sandstone uranium-vanadium deposits in the Salt Wash and Recapture members of the Morrison Formation are restricted to the east Carrizo Mountains (including the King Tutt Mesa area), and Chuska Mountains subdistricts of the Shiprock district, western San Juan Basin. Production totals 493,535 lbs of U_3O_8 (Table 2) for these districts. The Salt Wash Member is the basal member of the Morrison Formation and is overlain by the Brushy Basin Member (Anderson and Lucas, 1992, 1995; McLemore and Chenoweth, 1997). It unconformably overlies the Bluff-Summerville Formation, using older stratigraphic nomenclature (Anderson and Lucas, 1992), or the Wanakah Formation as proposed by Condon and Peterson (1986). The Salt Wash Member consists of 190-220 ft of interbedded fluvial sandstones and floodplain mudstones, shales, and siltstones. The mudstone and siltstone comprise approximately 5 to 45 percent of the total thickness of the unit (Masters et al., 1955; Chenoweth, 1993).

These tabular uranium deposits are generally elongated parallel to paleostream channels and are associated with carbonized fossil plant material. A cluster of small ore bodies along a trend could contain as much as 4,000 tons of ore averaging 0.23 percent U_3O_8 (Hilpert, 1969; Chenoweth and Learned, 1984; McLemore and Chenoweth, 1989, 1997). They tend to form subhorizontal clusters that are elongated and blanket like. Ore bodies in the King Tutt Mesa area are small and irregular. Only a few ore bodies have yielded more than 1,000 lbs of U_3O_8. A typical ore body in the King Tutt Mesa area is 150-200 ft long, 50-75 ft wide, and approximately 5 ft thick (McLemore and Chenoweth, 1989, 1997). The deposits are typically concordant to bedding, although discordant lenses of uranium-vanadium minerals crosscut bedding planes locally. The ore bodies typically are found in the middle of the sandstone bed, but locally, they are found at the interface between sandstone and less permeable shale or siltstone. However, unlike uranium deposits in the Grants district, the deposits at King Tutt Mesa are high in vanadium. The uranium:vanadium (U:V) ratio averages 1:10 and ranges 1:1 to 1:16.

The deposits in the Saltwash Sandstone Member are largely black to red, oxidized, and consist of tyuyamunite, meta-tyuyamunite, uranium and organic compounds, and a variety of vanadium minerals, including vanadium clay (Corey, 1958). Uranium and vanadium minerals are intimately associated with detrital organic material, such as leaves, branches, limbs, and trunks, derived from adjacent sandbar, swamp, and lake deposits, and humates. Small, high-grade ore pods (>0.5 percent U_3O_8) were associated with fossilized wood. The uranium-vanadium minerals form the matrix of the mineralized sandstones and locally replace detrital quartz and feldspar grains. Mineralized beds are associated with coarser-grained sandstone, are above calcite-cemented sandstone or mudstone-siltstone beds, are associated locally with mudstone galls, and are near green-to-gray mudstone lenses. Limonite is commonly associated with the ore bodies (Masters et al., 1955). Field and petrographic data suggests that the uranium-vanadium deposits formed shortly after deposition of the host sediments (Hilpert, 1969).

The majority of the uranium in the upper Recapture Member of the Morrison Formation is confined to a zone of light-gray sandstone with a maximum thickness of 60 ft which occurs from 10 to 170 ft below the Recapture-Westwater Canyon contact. Mineralized zones range from 20 to 300 ft in length and from a few inches to 20 ft in thickness.

Two types of uranium occurrences are found in the upper unit of the Recapture Member (Blagbrough et al., 1959). In the first, uranium occurs above or below a mudstone or siltstone unit, in a medium- to fine-grained, light-gray sandstone. The siltstone or mudstone is commonly 2 or 3 ft thick and is altered from red-to-green. The mineralized zone is a few inches to 2 ft thick and ranges in grade from a trace to as much as one percent U_3O_8. Uranium is fairly continuous along the siltstone or mudstone unit, and some uraniferous zones can be followed for a distance of 300 ft. The richest deposits occur along mudstones, which lie unconformably on sandstones; deposits along siltstones are commonly low grade.

The second type of mineralized zone ranges in thickness from a few inches to 20 ft and has a lateral extent of as much as 300 ft. The uranium is in a medium- to fine-grained, light-gray, thick sandstone lens and occurs as a halo around lime concretions that range in diameter from a few inches to 6 ft. Thin, irregular stringers and pebbles of mudstone and siltstone also have halos of uranium which are as much as 3 ft thick. The mudstones are chiefly red, but siltstones are altered to green. Uranium is also found in sandstone lenses containing red mudstone galls. Where the uranium forms a halo around and impregnates the galls, the mineralization it is commonly 1 or 2 ft thick. A thick mudstone or siltstone usually underlies the mineralized sandstones, and the lens is capped with an altered mudstone or siltstone.

Modeling of the regional groundwater flow in the Colorado Plateau during Late Jurassic and Early Cretaceous times supports the brine-interface model for these deposits and indicates that the regional groundwater flow was to the northeast in the King Tutt Mesa area (Sanford, 1982). In the King Tutt Mesa area, the bleaching of the sandstones and the geometry of tabular uranium-vanadium bodies support the reaction of two chemically different waters, most likely a dilute meteoric water and saline brine from deeper in the basin (McLemore and Chenoweth, 1997). The intimate association of uranium-vanadium minerals with organic material, further indicates that the uranium and vanadium were deposited at the same time.

Redistributed Uranium Deposits in the Cretaceous Dakota Sandstone

A total of 501,169 lbs of U_3O_8 has been produced from redistributed uranium deposits in the Dakota Sandstone in the Grants uranium district (McLemore, 1983; Chenoweth, 1989b). These deposits are similar in form and size to redistributed uranium deposits in the Morrison Formation and are found near primary and redistributed deposits in the Morrison Formation. Deposits in the Dakota Sandstone are typically tabular masses that range in size from thin pods a few ft long and wide to masses as much as 2,500 ft long and 1,000 ft wide. The larger deposits are only a few ft thick, but a few are as much as 25 ft thick (Hilpert, 1969). Ore grades ranged from 0.12 to 0.30 percent U_3O_8 and averaged 0.21 percent U_3O_8. Uranium is found with carbonaceous plant material near or at the base of channel sandstones, or in carbonaceous shale and lignite. The uranium is found along fractures, joints, or faults and within underlying permeable sandstone of the Brushy Basin or Westwater Canyon members.

The largest deposits in the Dakota Sandstone are found in the Old Church Rock mine in the Church Rock subdistrict of the Grants district, where uranium is associated with a major northeast-trending fault. More than 188,000 lbs of U_3O_8 have been produced from the Dakota Sandstone in the Old Church Rock mine (Chenoweth, 1989b).

Limestone Uranium Deposits in the Jurassic Todilto Formation

The oldest Jurassic-age uranium deposits in the Grants uranium district are limestone deposits in the Todilto limestone. Uranium is found only in a few limestones in the world, but the deposits in the Jurassic Todilto limestone are some of the largest and most productive (Chenoweth, 1985b; Gabelman and Boyer, 1988). Uranium minerals were found in the Todilto limestone in the early 1920s, although it was Paddy Martinez's discovery in 1950 that resulted in development of the Grants district. From 1950 through 1981, mines in the Grants district yielded 6,671,798 lbs of U_3O_8 from the Todilto limestone, amounting to approximately 2 percent of the total uranium produced from the Grants district (Chenoweth, 1985b; McLemore and Chenoweth, 1989, 1991).

Limestone is typically an unfavorable host rock for uranium because of relatively low permeability and porosity, and lack of precipitation agents such as organic material. However, a set of unusual geological circumstances allowed the formation of uranium deposits in the Todilto limestone. The organic-rich limestones were deposited in a sabkha environment on top of the permeable Entrada Sandstone. The overlying sand dunes of the Wanakah Formation (formerly Summerville Formation) locally deformed the Todilto muds, producing the intraformational folds in the limestone. Uraniferous waters derived from a highland to the southwest migrated through the Entrada Sandstone. Groundwater migrated into the Todilto limestone by evapotranspiration or evaporative pumping. Uranium precipitated in the presence of organic material within the intraformational folds and associated fractures in the limestone (Fig. 4; Rawson, 1981; Finch and McLemore, 1989). The Todilto uranium deposits formed 150-155 million years ago (Ma), based on uranium-lead (U-Pb) isotopic dating, and are older than the 130 Ma Morrison Formation sandstone uranium deposits (Berglof, 1989; Berglof and McLemore, 2003).

More than 100 uranium mines and occurrences are found in the Todilto limestone in New Mexico; 42 mines have documented uranium production (McLemore, 1983; McLemore and Chenoweth, 1989; McLemore et al., 2002). Most of these are in the Grants uranium district, although minor occurrences are found in the Chama Basin (Abiquiu and Box Canyon areas), Nacimiento district, and Sanostee in the Chuska Mountains. Minor mineralization extends into the underlying Entrada Sandstone or overlying Wanakah Formation in some areas. Uranium is found in the Todilto limestone only where gypsum-anhydrite beds are absent (Hilpert, 1969). At least one company is actively exploring for uranium in the Todilto limestone in the Grants uranium district.

Collapse-Breccia Pipe and Clastic Plug Deposits

Uraniferous collapse-breccia pipe deposits were mined in northern Arizona for uranium beginning in 1951 and continuing into the 1980s; average production grades of 0.5-0.7 percent U_3O_8 were common. Similar deposits are found in the Grants uranium district. Uraniferous collapse-breccia pipes are vertical or steeply dipping cylindrical features bounded by ring fractures and faults, and are filled with a heterogeneous mixture of brecciated country rocks containing uranium minerals. The pipes were probably formed by solution collapse of underlying limestone or gypsum (Hilpert and Moench, 1960; McLemore, 1983; Wenrich, 1985).

More than 600 breccia pipes are found in the Ambrosia and Laguna subdistricts, but only a few are uranium bearing (Moench, 1962; Nash, 1968; Hilpert, 1969). Pipe structures in the Cliffside (Clark and Havenstrite, 1963), Doris (Granger and Santos, 1963), and Jackpile-Paguate mines (Hilpert and Moench, 1960) have yielded ore as part of mining adjacent sandstone deposits; the exact tonnage attributed to these breccia pipes is not known. Very little brecciation has occurred at the Cliffside and Doris pipes, however, these pipes appear to be related to other breccia pipes in the area. The Woodrow deposit is the largest uranium producer from a breccia pipe in New Mexico (McLemore, 1983), and is 24 to 34 ft in diameter and at least 300 ft high. The New Mexico breccia-pipe deposits are similar in form to the Arizona breccia pipes, but are lower in grade and smaller size. In Arizona, the mineralized Orphan Lode breccia pipe is 150 to 500 ft in diameter

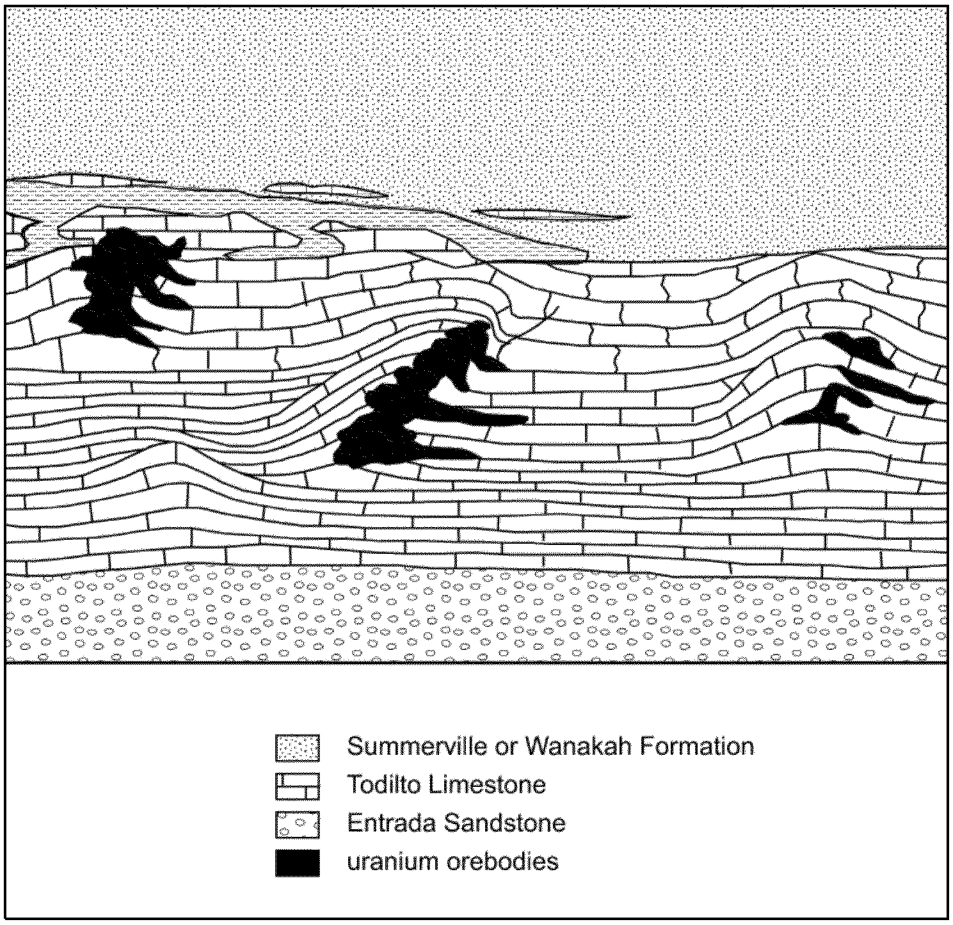

Figure 4. Control of Todilto uranium deposits by intraformational folds and fractures (modified from Finch and McLemore, 1989).

and at least 1,500 ft long (Gornitz and Kerr, 1970). More than 134,000 lbs of U_3O_8 at a grade of 1.26 percent U_3O_8 was produced from the Woodrow deposit. However, the New Mexico uraniferous collapse-breccia pipes are uncommon and much smaller in both size and grade than the Arizona uraniferous collapse-breccia pipes. Future mining potential of New Mexico breccia pipes is unknown. Additional research is needed to understand why some pipes are mineralized and others are not, and to determine the extent of mineralized breccia pipes in New Mexico.

SOURCE OF URANIUM

The source of the uranium and vanadium deposits in the Todilto limestone and Morrison Formation sandstones is not well constrained. The uranium could be derived from alteration of volcanic detritus and shales within the Morrison Formation that were erupted from volcanoes forming the Jurassic arc (Fig. 5; Thamm et al., 1981; Adams and Saucier, 1981; Turner-Peterson, 1985; Turner-Peterson and Fishman, 1986) or from groundwater derived from a volcanic highland to the southwest, i.e. the Jurassic arc (Sanford, 1982, 1992). The source of uranium is important in understanding how the Grants deposits formed, establishing United States Geological Survey (USGS) geologic deposit type and geoenvironmental models, and locating additional uranium provinces elsewhere in the world.

The age of the uranium deposits in the Grants district is constrained by numerous isotopic studies (Table 1; Fig. 6) and supports a potential Jurassic arc as the source. Jurassic volcanism, intra-arc sedimentation and plutonism are well documented throughout the Jurassic arc (Saleeby and Busby-Spera, 1992; Miller and Busby, 1995; Blakey and Parnell, 1995; Lawton and McMillan, 1999; Kowallis et al., 2001; du Bray, 2007).

Another potential source of uranium in the Grants district is a Proterozoic granitic highland, enriched in uranium, which lies south of the district, i.e. the Zuni Mountains. Gruner (1956) proposed that weathering and erosion of Proterozoic granitic rocks could have released large quantities of uranium, which along with uranium derived from volcanic ash, would have been sufficient to produce the uranium deposits in the Grants district. Silver (1977) was one of the first to note a regional anomaly in

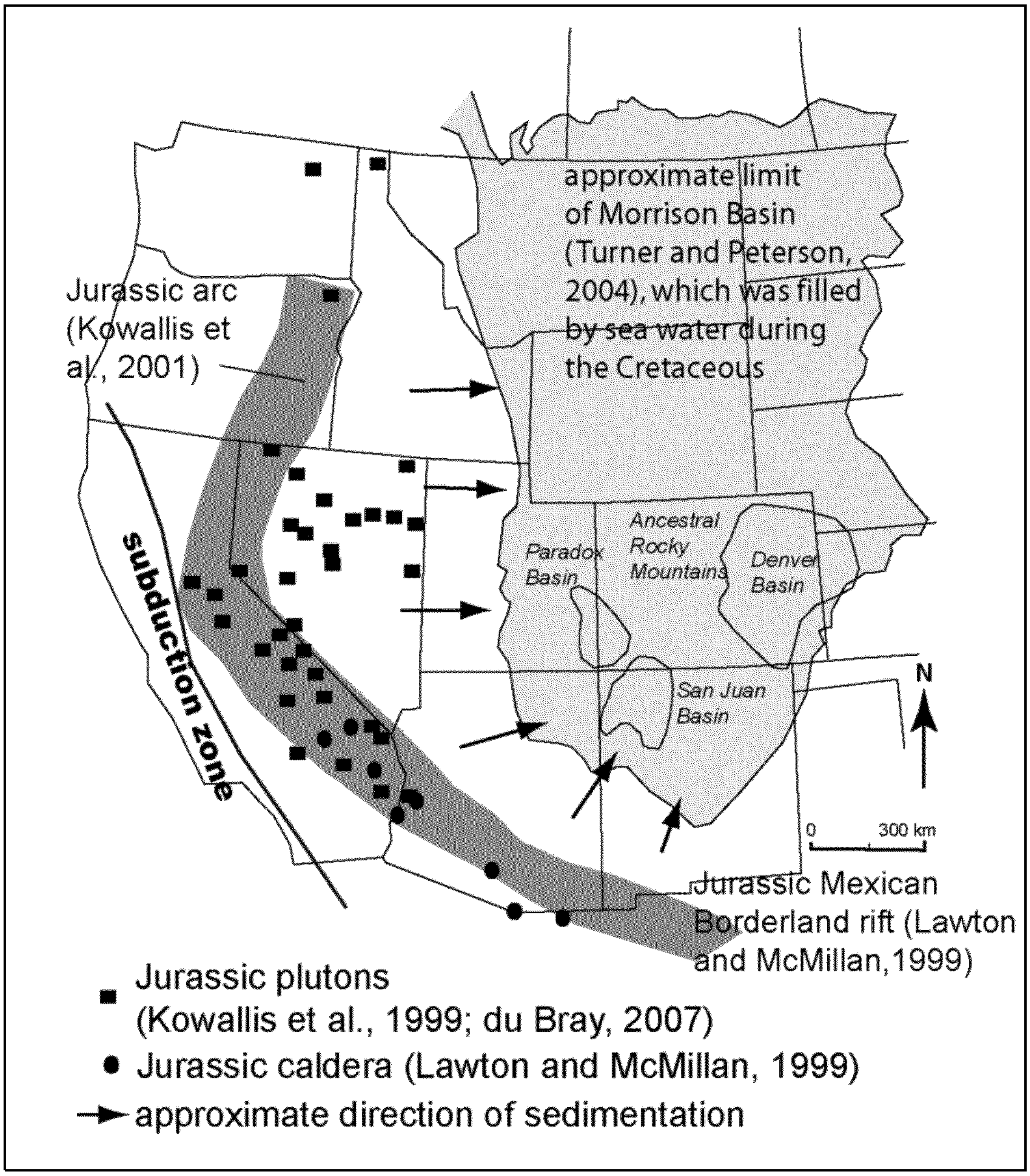

Figure 5. Approximate location of the Jurassic arc in relation to the Morrison Basin. The Grants uranium district is in the southern San Juan Basin.

uranium concentration in the Proterozoic basement granitic rocks of the Colorado Plateau. The Zuni Mountains area, south and southwest of the Grants district, is known for its high heat flow of approximately 2-2.5 heat flow units (Reiter et al., 1975), and Proterozoic granites in the Zuni Mountains contain as much as 11 parts per million uranium (Brookins and Rautman, 1978), thus suggesting that these granites could have been a local uranium source.

Uranium leached from the altered volcanic ash and from erosion of the Proterozic granitic highland could have been carried by ground and surface waters into the Todilto limestone and later into the Morrison Formation, forming the uranium deposits found in the Grants district. The presence of organic material caused the precipitation of the uranium in the uranium deposits, as summarized in Table 4.

FUTURE POTENTIAL

In 2002, the DOE estimated New Mexico contained known resources of 15 million tons of ore at 0.28 percent U_3O_8 (84 million lbs U_3O_8) at a forward cost of $30 per lb and 238 million tons of ore at 0.076 percent U_3O_8 at a forward cost of $50 per lb, ranking second in uranium resources in the US behind Wyoming (Energy Information

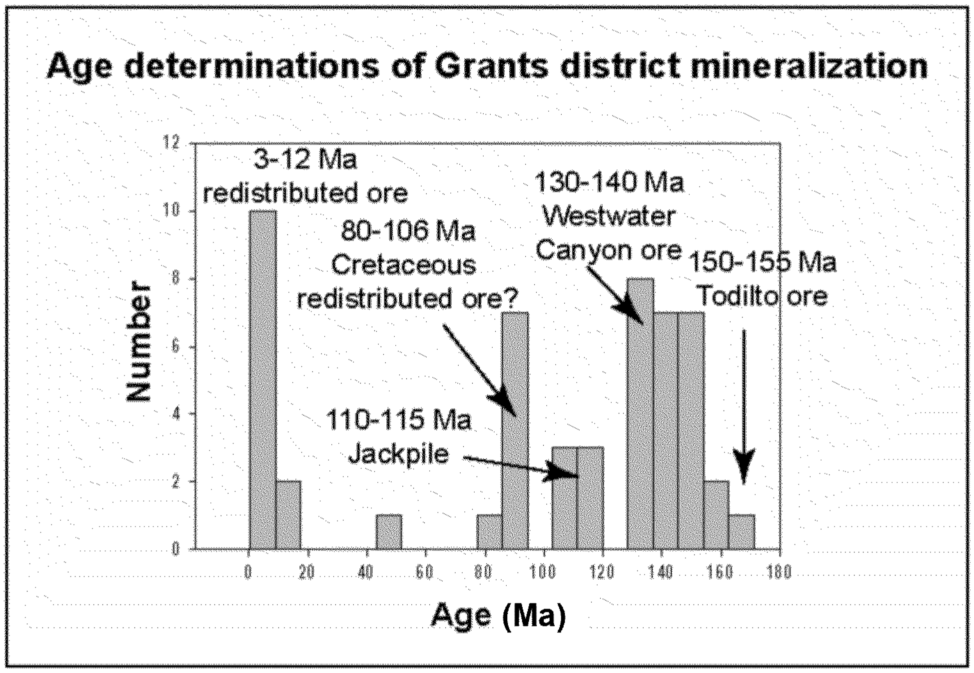

Figure 6. Age determinations of Grants district mineralization. Includes Pb/U, K/Ar, Rb/Sr, and fission track dates from Miller and Kulp (1963), Nash and Kerr (1966), Nash (1968), Berglof (1970, 1989), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983) and is summarized by Wilks and Chapin (1997).

Administration, 2006). The DOE classifies uranium reserves into forward cost categories of $30 and $50 U_3O_8 per lb. Forward costs are operating and capital costs (in current dollars) that are still to be incurred to produce uranium from estimated reserves.

Only one company in New Mexico, the Quivira Mining Co. (successor to Kerr-McGee Corp., now owned by BHP-Billiton Plc.), produced uranium in 1989-2002, from waters recovered from inactive underground operations at Ambrosia Lake (mine-water recovery). Quivira Mining Co. is no longer producing uranium and the Ambrosia Lake mill and mines are reclaimed.

Rio Grande Resources Co. is maintaining the closed facilities at the flooded Mt. Taylor underground mine in Cibola County, where primary sandstone-hosted uranium deposits were mined as late as 1989. Reserves are estimated as 30,250,000 lbs U_3O_8 at 0.25 percent U_3O_8, which includes 7.5 million lbs of U_3O_8 at 0.50 percent U_3O_8 (Table 3). Depths to ore average 3,300 ft.

Several other companies are actively exploring for or permitting uranium resources in New Mexico (Table 3). Laramide Resources Ltd. controls the La Jara Mesa uranium deposit in Cibola County, formerly owned by Homestake Mining Co. and Anaconda. This primary sandstone-hosted uranium deposit, discovered in the Morrison Formation in the late 1980s, contains 7,257,817 lbs of ore averaging 0.25 percent U_3O_8 (Table 3). It is above the water table and is not suited to traditional in situ leaching technologies. New Mexico Mining and Minerals Division has approved an exploration permit for Laramide Resources Ltd. and a permit is pending for Urex Energy Corp., who also owns adjacent properties to Laramide on Jara Mesa. Laramide Resources Ltd. also controls the nearby Melrich deposit (Table 3). Lakeview Ventures also acquired adjacent properties.

Hydro Resources, Inc. (subsidiary of Uranium Resources Inc.) is waiting for final permit approvals and an increase in the price of uranium before mining uranium by in situ leaching at Church Rock and Crownpoint. Production costs are estimated at $13.54 per lb of U_3O_8 (Pelizza and McCarn, 2002, 2003a, b). Reserves at Church Rock (Section 8 and Section 17 mines) and Mancos mines are estimated as 19 million lbs of U_3O_8 (Table 3; Pelizza and McCarn, 2002, 2003a, b). Hydro Resources, Inc. estimates production costs at Crownpoint to be between $11.46 and $12.71 per lb U_3O_8 (Pelizza and McCarn, 2002, 2003a, b). Hydro Resources, Inc. also controls Santa Fe Railroad properties in the Ambrosia Lake subdistrict.

Strathmore Minerals Corp. has acquired numerous properties in the Grants district, including Roca Honda, Church Rock, and Nose Rock (Table 3). Strathmore hopes to mine uranium by both in situ leaching and conventional mining and milling. Mining permits are pending for the Roca Honda deposit.

Other properties are listed in Table 3. All of New Mexico's uranium reserves in the DOE estimates are in the Morrison Formation in the San Juan Basin, although exploration is occurring elsewhere in New Mexico. Compilation of company data suggests that approximately 403 million lbs of U_3O_8 remain as unmined resources (Table 3). Any conventional mining of uranium in New Mexico will require a new mill or the ore would have to be shipped to the White Mesa mill near Blanding, Utah.

TABLE 4

Sequence of uranium deposition in the Grants district (from youngest to oldest). The age of the mineralizing event is from isotopic dating (Fig. 6) or is estimated by the author based upon stratigraphic position.

Depositional Event	Age	Reference
Secondary Todilto limestone deposits	Tertiary, 3-7 Ma	Berglof (1989)
Redistributed uranium deposits (Cretaceous Dakota Sandstone, Jurassic Brushy Basin and Westwater Canyon Sandstone members)	Tertiary, 3-12 Ma	Miller and Kulp (1963), Nash and Kerr (1966) , Nash (1968), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983)
Redistributed uranium deposits (Cretaceous Dakota Sandstone, Jurassic Brushy Basin and Westwater Canyon Sandstone members)	Cretaceous, 80-106 Ma	Smith, R., and V.T. McLemore (unpublished)
Uranium in the Jackpile sandstone	110-115 Ma	Lee (1976)
Uranium in the Poison Canyon sandstone	Unknown, estimated 130-115 Ma	
Uranium in the Brushy Basin Sandstone Member	Unknown, estimated 130-115 Ma	
Uranium in the Westwater Canyon Sandstone Member	148-130 Ma	Miller and Kulp (1963), Nash and Kerr (1966) , Nash (1968), Brookins et al. (1977), Brookins (1980), Ludwig et al. (1982), Hooper (1983)
Deposition of the Morrison Formation units	Unknown, estimated before 130 Ma	
Todilto limestone uranium deposits	155-150 Ma	Berglof (1970, 1989)
Deposition of the Todilto limestone	Before 155 Ma	

SUMMARY

Sandstone and limestone uranium deposits in New Mexico have played a major role in historical uranium production. Although worldwide other types of uranium deposits are higher in grade and larger in tonnage, the Grants uranium district has been a significant source of uranium and has the potential to become an important future source, as low-cost technologies, such as in situ leaching techniques improve, and as demand for uranium increases, increasing the price of uranium. However, several challenges need to be overcome by the companies before uranium could be produced once again from the Grants uranium district:

- There are no conventional mills remaining in New Mexico to process the ore, which adds to the cost of producing uranium in the state. Currently all conventional ore must be processed by the White Mesa Mill in Utah or heap leached on site. New infrastructure will need to be built before conventional mining can resume.
- Permitting for new in situ leaching, especially for conventional mines and mills, will take years to complete.
- Closure plans, including reclamation, must be developed before mining or leaching begins. Modern regulatory costs will add to the cost of producing uranium in the US.
- Some communities, especially the Navajo Nation communities, do not view development of uranium proper-

ties as favorable. The Navajo Nation has declared that no uranium production will occur on Navajo lands. Most of Mt. Taylor and adjacent mesas have been designated as the Mt. Taylor Traditional Cultural Property; the effect of this designation on uranium exploration and mining is uncertain.
- High-grade, low-cost uranium deposits in Kazakhstahn, Canada and Australia are sufficient to meet current international demands; additional resources will be required to meet long-term future requirements.

ACKNOWLEDGMENTS

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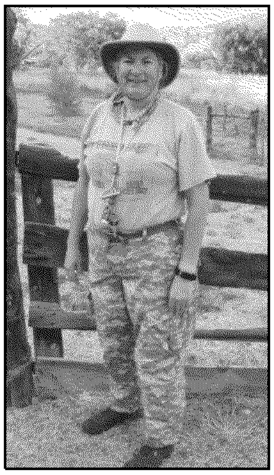
THE AUTHOR

VIRGINIA T. MCLEMORE



VIRGINIA "GINGER" MCLEMORE is a Senior Economic Geologist with the New Mexico Bureau of Geology and Mineral Resources at New Mexico Tech. Ginger received B.S. degrees in Geology and Geophysics, and an M.S. degree in Geology from New Mexico Tech. She received her Ph.D. in Geoscience from the University of Texas at El Paso in 1993. Ginger began work with the New Mexico Bureau of Geology and Mineral Resources in 1980 as an economic geologist specializing in uranium deposits. She has published numerous articles on the mineral resources of New Mexico, including New Mexico gold and silver deposits, and uranium deposits. Her current projects include investigating minerals required for emerging "green" technologies, uranium, beryllium, and rare-earth elements in New Mexico; alkaline magmatism, carbonatites, anorthosites, A-type granites, and mineral deposits in New Mexico. She also is an adjunct professor and teaches Geology of Industrial Minerals, Uranium Geology, and two graduate level courses for the Department of Earth and Environmental Sciences and the Department of Mineral Engineering at New Mexico Tech.